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Controlling Monopoly Power in a Double-Auction Market Experiment*

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Abstract

There is robust evidence in the experimental economics literature showing that monopoly power is affected by trading institutions. In this paper we study whether trading institutions themselves can shape agents' market behaviour through the formation of anchors and reference points. We recreate experimentally five different double-auction market structures (perfect competition, perfect competition with quotas, cartel on price, cartel on price with quotas, and monopoly) in a within-subject design, varying the order of markets implementation. We investigate whether monopoly power endures the formation of reference prices emerged in previously implemented market structures. Results from our classroom experiments suggest that double-auction trading institutions succeed in preventing monopolists to exploit their market power. Furthermore, the formation of reference points in previously implemented markets negatively impacts on monopolists' power in later market structures.

Keywords: Double Auctions; Perfect Competition; Monopoly, Market Imperfection; Spillovers; Classroom Experiments;
JEL code: C90, D41, D42, D43, D44

1 Introduction

The quest on controlling market power has paved the way to the modern experimental economics literature. Since the seminal works by Chamberlin [1948] and Smith [1962], scholars have tried to show that the power of agents operating in markets can be sensitive to the trading mechanisms devised. For example, Smith and Williams [1981] conducted a series of laboratory market experiments designed to investigate whether the rules of market trading mechanisms might discipline a monopolist. It turned out that public posting of uniform prices in a Posted Offer Auction eliminates the incentive to offer discounts on marginal units that arises in a Double Auction. Indeed, prices set by monopolists under double-auction trading mechanisms are significantly lower than those the theory predicts, converging towards perfect-competition levels.[1] On the other hand, recent experimental work

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[1]Similar results are reported in Holt et al. [1986], Smith and Williams [1989], and Davis and Williams [1991].

has also provided conflicting evidence. Muller et al. [2002] seek evidence proving double-auction markets being able to control over monopoly and monopsony power. The authors find that double-auction trading mechanisms provide an ineffective constraint to market power and do not succeed in preventing agents with market power from exploiting their advantage. Similar results are reported in Ledyard and Szakaly-Moore [1994], Brown-Kruse et al. [1995], and Godby [2000, 2002].

While the choice of the trading mechanisms has a significant impact on monopolistic market equilibrium, it is not clear how the presence of behavioural tendencies, combined to that of particular trading mechanisms may affect monopoly power. It is common wisdom in the experimental literature that subjects use formerly traded prices as *reference points*, namely, the regular price that they expect to pay for a given good (Thaler [1985], Isoni et al. [2011], Bordalo et al. [2012], Putler [1992]). Seminal works in the experimental economics literature have proven the ubiquitous presence of such anomalies in subjects' behaviour, even in repeated trading interactions. The *shaping hypothesis* proposed by Loomes et al. [2003] for example, states that in repeated auctions in which prices have no information content, there is a tendency for agents to adjust their bids towards the price observed in the previous market period. Tufano [2010] shows that market behaviour is not anomaly-free, strengthening Loomes and coauthors' results. Also out-of-the-lab studies of auctions have shown that game history and subjects' experience do matter in the analysis of price convergence, bids and sold quantity. Pownall and Wolk [2013] show that experience significantly lowers the level of bids suggesting that bidders change their bidding behavior throughout time, eventually eliminating previous overbidding. These studies confirm that market behaviour is not the product of the underlying true preferences but rather of context-dependent preferences.

Drawing from this experimental evidence, we design a double-auction classroom experiment with undergraduate students in Economics to understand whether the implementation of double-auction trading institutions creates a constraint over monopoly power and whether such effect is modulated by the formation of reference points created in previous markets. In particular, we hold double-auction trading under different market structures – perfect competition with and without quotas, cartel with and without quotas, monopoly – and vary, across treatments, their implementation order. With this, we aim at investigating whether monopoly power depends on subjects' experienced prices under previously-implemented market structures.

Our results provide indication that, under double-auction trading, prices prevailing in monopolistic markets are far lower than those predicted by the theory. On average, prices in monopoly start out relatively low since the first period, to then decrease as the experiment unravels. Moreover, if the monopoly comes after other market structures, the formation of reference prices in prior market structures weakens the monopolist's market power. In particular, when subjects in the experiment first trade under perfect competition, prices are lowest than when either cartel or no market precedes the monopoly.

The remainder of the paper is as follows: Section 2 discusses the experimental design and theoretical predictions, in Section 3 we present our hypotheses, and Section 4 reports the experimental results. Lastly, Section 5 concludes.

2 Experimental design

2.1 Market structures

Following Smith [1962] and subsequent standard practice in market classroom experiments (see, e.g., Holt [1996], Cason and Friedman [2008]; Attanasi et al. [2016]), we recreate an experimental, computerized double-auction laboratory market. Table 1 describes the main features of each market structure of our design.

Table 1: Market structures

Market	**No. Buyers**	**No. Sellers**	**No. Markets**	**Q per Seller**
Perf. Comp.	24	4	1	24
Perf. Comp. - *quotas*	24	4	1	6
Cartel	24	4	1	24
Cartel - *quotas*	24	4	1	6
Monopoly	6	1	4	6

We implement overall a total of five market structures in a within-subject design. In each experimental session, $n = 28$ subjects are randomly assigned to the role of seller or buyer: 4 of them are sellers and the remaining 24 are buyers. Subjects keep the same role for the whole experiment. They play the five market structures in Table 1. Every market structure is played for 3 periods and a single trading period lasts 120 seconds. At the beginning of the experiment, subjects only know that the experiment is made of five phases (market structures), with instructions of each new phase distributed only prior to that phase.

In each trading period, sellers' costs and buyers' valuations of a homogeneous good are exogenously given: each buyer is endowed with a valuation v_i, which varies across buyers, while the four sellers face the same production cost c. Although the former is public information, buyers (sellers) only know their own valuation (cost). Valuations are described by the step function with values $v_i \in \{20, 18, 16, 14, 12, 10\}$ (see Figures A1, A2, A3, and A4 in the Appendix). More precisely, in each trading period there are 4 buyers with the same v_i (i.e., 4 buyers with $v_1 = 20$, 4 buyers with $v_2 = 18$, ..., 4 buyers with $v_6 = 10$). The cost c is set at 12 for every seller. Valuations and re-shuffled are randomly re-assigned to buyers at each trading period.

For each seller-buyer transaction, the profit of seller S_j ($j = 1, 2, 3, 4$) is given by the difference between the trading price and his production cost, $\Pi_{S_j} = p - c$; the profit of buyer B_k is given by the difference between the assigned valuation and the trading price, formally $\Pi_{B_k} = v_{ik} - p$. Neither non-positive profits nor transferring positive profits from one trading period to another is allowed (every time a new period starts, subjects' profits are reset to zero). Due to the short duration of trading periods, sellers' asks and buyers' bids are constrained to be integer numbers between 0 and 30, and each buyer can buy at maximum one unit of the good in each trading period. However, in line with our research objective, sellers are allowed to sell more than one unit of the good.

Trading is done through a double-auction mechanism. During the trading period, subjects are always shown the current highest bid and lowest ask. Every subject can improve on the existing situation (*improvement rule*): A buyer can submit a

bid only if higher than the current highest bid (ascending auction), and a seller can submit an ask only if lower than the current lowest ask (descending auction). When a buyer and a seller reach an agreement, they exit the market, the standing bids and asks are removed, and new bids and asks can be submitted without taking into account the previous trading price (*market clearing rule*). The trading price, together with the IDs of the buyer and seller reaching that agreement, are disclosed on the screens of all subjects in chronological order.

All of the above is independent of the market structure. Let us now discuss in detail each of the five **market structures** presented in Table 1.

Perfect Competition. In each of the 3 trading periods, there are $m = 4$ sellers with $c = 12$, and $n = 24$ buyers with each buyer being randomly assigned one of the six v_i: 4 buyers have $v_1 = 20$, 4 have $v_2 = 18$, 4 have $v_3 = 16$, 4 have $v_4 = 14$, 4 have $v_5 = 12$, and 4 have $v_6 = 10$. Each seller owns 24 units of the homogeneous good, with which he can face alone all the buyers' demand. With this, the competitive market is characterized by 96 available units of the homogeneous good, with at most 24 of them being tradable.

Cartel. It is similar to Perfect Competition apart from the four sellers going through a pre-trading stage called "communication stage" in which they are asked to privately report their target trading price within $\{0, 1, ..., 30\}$.[2] The experimenter then disclose to the four sellers the resulting average among the four proposed prices. Buyers are informed about the rules of the communication stage, but not about the outcome. The communication stage is intended to allow sellers to form a price cartel. However, sellers are told that during the following double-auction trading they are not committed to offer the 24 buyers either their own or the average proposed price in the communication stage. Therefore, no additional constraint on trading is imposed with respect to Perfect Competition.

Perfect Competition with quotas and **Cartel with quotas**. Under both Perfect Competition and the Cartel structures, we distinguish between a "regular" market and one in which restrictions on the quantity endowed to sellers, called "quotas," are applied. In particular, in the latter each seller is only endowed with 6 units of the homogeneous good, with which he can face alone $1/4$ of the buyers' demand. With 4 sellers in the market, the total supply of 24 units is equal to the maximum quantity buyers can buy. This leads to other two market structures, with quotas: one under Perfect Competition and another under the Cartel structure.

Monopoly. The 28 subjects in the session are randomly allocated to 4 markets, with 1 seller and 6 buyers per market. Each market is characterized by the same supply function – the seller owning 6 units of the good at a cost of $c = 12$ each –, and the same demand function – with each of the six buyers being assigned one of the six possible valuations $v_i \in \{20, 18, 16, 14, 12, 10\}$. In each of the four monopolistic markets the trading mechanism is still Double Auction, so that price discrimination is allowed for each of the units traded within a period.

[2]Note that, to preserve subjects' anonymity and to have the same bargaining rules in each Cartel session, sellers cannot chat or send proposals among them.

2.2 Theoretical Predictions

We now derive equilibrium quantity and price in each of the five markets.

Perfect Competition. The demand and supply functions in Figure A1, together with the discrete set of possible prices $\{0, 1, ...30\}$, and the experimental requirement for both sellers and buyers to make at least 1 point of profit (non-positive profits are not allowed), lead to an equilibrium quantity and price under Perfect Competition of $(Q^*_{Co}, p^*_{Co}) = (16, 13)$, i.e., 66% of buyers (16/24) trade in equilibrium. Each seller sells on average 6 of his 24 units, although any supply vector $(q^*_j)^4_{j=1}$ with $q^*_j \in \{0, 1, ..., 24\}$ and $\sum^4_{j=1} q^*_j = 24$ is an equilibrium. Figure A1 also represents the sellers' total surplus, equal to 16 (1 point per traded unit).

Cartel. The equilibrium quantity and price depend on whether sellers reach a mutual agreement on prices to maximise the sellers' total surplus. If they reach such agreement, the quantity-price combination maximising the sellers' total surplus is $(Q^*_{Ca}, p^*_{Ca}) = (8, 17)$, i.e., only 33% of buyers (8/24) trade in equilibrium, with each seller only selling on average 2 of his 24 units (equilibrium supply vector $(q^*_j)^4_{j=1}$ with $q^*_j \in \{0, 1, ..., 8\}$ and $\sum^4_{j=1} q^*_j = 8$). Figure A2 shows that in this case the sellers' total surplus equals to 40 overall (5 points per traded unit).[3] However, in our setting agreements are not binding and there is an individual incentive to deviate. If sellers do not maintain the above-mentioned cartel agreement, the quantity-price combination is the same as under Perfect Competition, i.e., $(Q^*_{Ca}, p^*_{Ca}) = (Q^*_{Co}, p^*_{Co}) = (16, 13)$.

Perfect Competition with quotas and **Cartel with quotas**. The introduction of quotas does not impact on the market equilibrium values in either Perfect Competition or Cartel. In fact, given a quota of 6 units per seller, the total supply of 24 units is sufficient to guarantee $Q^*_{Co} = 16$ and $Q^*_{Ca} = 8$, respectively. However, the equilibrium supply vector $(q^*_j)^4_{j=1}$ is constrained to $q^*_j \in \{0, 1, ..., 6\}$, with $\sum^4_{j=1} q^*_j = 16$ under Perfect Competition (Figure A1) and $\sum^4_{j=1} q^*_j = 8$ under the Cartel (Figure A2). Therefore, given that none of the sellers is able to satisfy alone all the equilibrium market demand in any of the two market configurations, the lower pressure on the supply side may eventually lead to an increase in the traded price and lower the traded quantity. This effect should be greater in the Cartel (with quotas), since sellers can account for the individual rationing when reporting their (higher) target trading price in the communication stage and when trying to maintain it throughout the three trading periods.

Monopoly. Here we have to distinguish the two cases of Monopoly with Unique price (*Mo-U*) and Monopoly with price Discrimination (*Mo-D*). The quantity-price combination under unique price would be $(Q^*_{Mo-U}, p^*_{Mo-U}) = (2, 17)$, hence only 33% (2/6) buyers would trade, as reported in Figure A3. In this case the surplus obtained by each monopolist would be equal to 10. Considering together the four monopolistic markets in each experimental session, the equilibrium quantity-price combination and the sellers' total surplus are the same as in the Cartel market structure (when a mutual agreement is reached and maintained), i.e., $Q^*_{Ca} = 4 \cdot Q^*_{Mo-U} = 8$ and $p^*_{Ca} = p^*_{Mo-U} = 17$. If the monopolist is able to discriminate instead (as it is

[3]Notice here that a price of 18 is not feasible since the buyer with a valuation of 18 in the experiment only trades if he gains at least 1 point from the transaction.

actually allowed in our experimental implementation of Monopoly), the vector of equilibrium prices will be $p^*_{Mo-D} = (19, 17, 15, 13)$, with equilibrium traded quantity $Q^*_{Mo-D} = 4$ (with 66% of buyers trading) and the monopolist's surplus equal to 16, as reported in Figure A4. In this case the four monopolistic markets considered together would lead to the same equilibrium quantity as under Perfect Competition, i.e., $Q^*_{Co} = 4 \cdot Q^*_{Mo-D} = 16$. However, the sellers' total surplus would be 64 (4 points per traded unit on average), i.e., four times as much than under Perfect Competition. In particular, under price discrimination, in each of the four monopolistic markets the unique seller would get the same surplus that the four sellers considered together would obtain under Perfect Competition.

2.3 Experimental Procedures and Treatments

Sessions were run in the Laboratory of Experimental Economics of Strasbourg (LEES) by two of the paper authors. The experiment was computerised using the online platform www.econplay.fr. Individual cubicles ensured subjects' anonymity and absence of communication during the experiment. Each session took place before tutorials of the first-year introductory course in Microeconomics, throughout three consecutive academic years (November–December, 2014–2016).

In total 1008 students participated in the experiment (336 per year), in 36 different sessions (12 sessions per year), and 28 students in each session. Each session was followed by a tutorial in Microeconomics, where the teacher (same as the experimenter) introduced the theoretical predictions of Section 2.2 to students, and then analysed and discussed the experimental data in the light of these predictions. Subjects were equally balanced in gender (45% female) and homogeneous in other features: age (almost all students were 18-20 years old), nationality (90% of them French) and field of study (Economics and Management). Subjects were not paid for participation and behavior during the experiment, as it is the standard for classroom experiments [see, e.g., Holt, 1996, 1999].

The experiment was implemented according to 12 treatments, with 3 sessions (Microeconomic classes) for each treatment. The 3 sessions of the same treatment were implemented in 3 non-consecutive classes. As Table 2 shows, in each of the 12 treatments students were presented, at a within-subject level, the five market structures described in Section 2.1: Perfect Competition (Comp), Perfect Competition with quotas (Comp-q), Cartel (Cartel), Cartel with quotas (Cartel-q), and Monopoly. The treatments differed at a between-subject level according to the order of presentation of the five market structures.

Given that each market structure was proposed for 3 consecutive trading periods, each treatment was characterized by 15 trading periods, with instructions of each new market structure being shown on the computer screen only at the end of the previous 3 trading periods. Each trading period lasting 120 seconds, the experimental session average duration was about 40 minutes, including the reading of instructions. An example of the computer screen of buyers and sellers during a trading period is reported in the Appendix (Figure A5 refers to the screen of buyer B_6 and Figure A6 refers to the screen of seller S_1, both in the first trading period of a market under Perfect Competition).[4]

[4]Figures A5-A6 show a moment of the trading period where 5 units are already traded (thus,

Table 2: Order of presentation of the five market structures

Treatments	Timeline				
	1	**2**	**3**	**4**	**5**
CoCaMo	Comp	Comp-q	Cartel	Cartel-q	Monopoly
CoMoCa	Comp	Comp-q	Monopoly	Cartel	Cartel-q
CaCoMo	Cartel	Cartel-q	Comp	Comp-q	Monopoly
CaMoCo	Cartel	Cartel-q	Monopoly	Comp	Comp-q
MoCoCa	Monopoly	Comp	Comp-q	Cartel	Cartel-q
MoCaCo	Monopoly	Cartel	Cartel-q	Comp	Comp-q
CoCaMo-q	Comp-q	Comp	Cartel-q	Cartel	Monopoly
CoMoCa-q	Comp -q	Comp	Monopoly	Cartel-q	Cartel
CaCoMo-q	Cartel-q	Cartel	Comp-q	Comp	Monopoly
CaMoCo-q	Cartel-q	Cartel	Monopoly	Comp-q	Comp
MoCoCa-q	Monopoly	Comp-q	Comp	Cartel-q	Cartel
MoCaCo-q	Monopoly	Cartel-q	Cartel	Comp-q	Comp

Note: 3 sessions for each treatment. 'Co', 'Ca', and 'Mo' stand for Perfect Competition, Cartel and Monopoly, respectively. The 'q' symbol following the name of a market structure indicates the presence of quotas.

Referring to Table 2, we report the main features of our order manipulation at a between-subject level:

- The first group of six treatments of Table 2 (first six rows of the table) share the common feature of implementing structures without quotas first, followed by those with quotas, while in the second group (last six rows of the table) the order is switched.
- Treatment 1 and treatment 7 (first row of each group of six treatments) indicates an order of markets presentation with decreasing structural level of competition (respectively, CoCaMo and CoCaMo-q).
- Treatment 6 and treatment 12 (last row of each group of six treatments) indicates an order of markets presentation with increasing structural level of competition (respectively, MoCaCo and MoCaCo-q).
- The remaining four rows of each group of six indicate treatments with an order of markets presentation leading to non-monotonic levels of competition.
- Row-to-row pairwise comparison between treatments in the first and in the second group of six allows us to test for the effect of quotas introduced vs. removed within the same market.

$24 - 5 = 19$ units are still available for purchase and $96 - 5 = 91$ are still available for sale), seller S_1 has sold 2 of these units, buyer B_6 has not bought yet, the current highest bid is 15 (by buyer B_{10}), and the current lowest ask is 16 (by seller S_4).

3 Hypotheses

Our research hypotheses are threefold. First we want to ensure that equilibrium prices under each market are in line with our predictions. If so, we ought to observe a *weak monotonicity* of prices.

Hypothesis 1. Prices increase or do not decrease by going from Perfect Competition to Monopoly, formally:

$$p_{Co} \leq p_{Co-q} \leq p_{Ca} \leq p_{Ca-q} \leq p_{Mo} \tag{1}$$

In order to test this hypothesis, we will only consider market structures played as first in the treatment timeline of Table 2. For example, we will gather prices of perfect competitive markets from each sequence starting with perfect competition (CoCaMo, CoMoCa, CoCaMo-q, and CoMoCa-q). Once having done so for each market structure, we will pass on testing inequalities of Hypothesis 1.

The second hypothesis concerns the monopoly power and especially whether monopoly power is affected by the order through which the market has been implemented.

Hypothesis 2. Monopoly power endures order effect: Prices observed in Monopolies played at the beginning are bigger than those observed in Monopolies played after Perfect Competition and/or Cartel.

The idea behind this hypothesis is to assess if Perfect Competition and Cartel represent *reference points* in later-presented monopolistic structures. Namely, prices of previously-presented markets can affect subjects' behaviour when operating in the monopolistic structure. In order to test this hypothesis (see Table 2), prices from all Monopolies played in the first position of a sequence (MoCoCa, MoCaCo, MoCoCa-q, and MoCaCo-q) are compared to those played as second (CoMoCa, CaMoCo, CoMoCa-q, and CaMoCo-q), and at the end of a sequence (CoCaMo, CaCoMo, CoCaMo-q, and CaCoMo-q).

Finally, our third hypothesis concerns to the ability of monopolists to price-discriminate depending on the order of presentation of this market in the treatment timeline.

Hypothesis 3. Monopolists are able to price-discriminate only when the Monopoly is played at first.

Differently from the second hypothesis, in our Hypothesis 3 we focus on the dispersion of price distributions. A more disperse distribution of prices is indicative of higher price discrimination.

4 Results

In order to test our predictions, we present the results in two steps. The first step concerns the study of first-played markets to shed light on Hypothesis 1 (H1). To test weak monotonicity of prices (see Eq. (1)), we look at trading prices when the market is played for the first time in the experiment so as to avoid any order effect.

Second, we compare trading prices of Monopoly when played after Perfect Competition, Cartel or both. Our aim in this second comparison is to test whether the formation of reference points in subjects creates spillovers affecting monopolistic market outcomes, according to Hypothesis 2 (H2) and Hypothesis 3 (H3).[5]

H1: Monotonicity of prices. Table 3 presents the summary statistics of trading prices observed in each of the five market structures played at first in the experiment. Figure 1 shows their distribution broken down by trading period. Given that no significance difference is found between Comp and Comp-q (t-test, *P-value* $= 0.849$) and between Cartel and Cartel-q (t-test, *P-value* $= 0.187$), Figure 1 only shows the distribution of trading prices for the three market structures without quotas: Comp, Cartel and Monopoly.

Trading prices under Perfect Competition are in line with the theoretical prediction (Figure 1, panel *Comp*): they are, on average, slightly above the prediction $p^*_{Co} = 13$, and converge to such level as market interaction unravels across periods.

From panel *Cartel* in Figure 1, it is striking how the median of the distribution of Cartel prices in period 1 is very close to the theoretical prediction when the Cartel agreement is maintained ($p^*_{Ca} = 17$) and then shifts towards $p^*_{Co} = 13$ in periods 2-3. It thus emerges that although sellers reach a mutual agreement on the (higher) trading price, they are not able to maintain it across periods (Huck et al. [2001]).

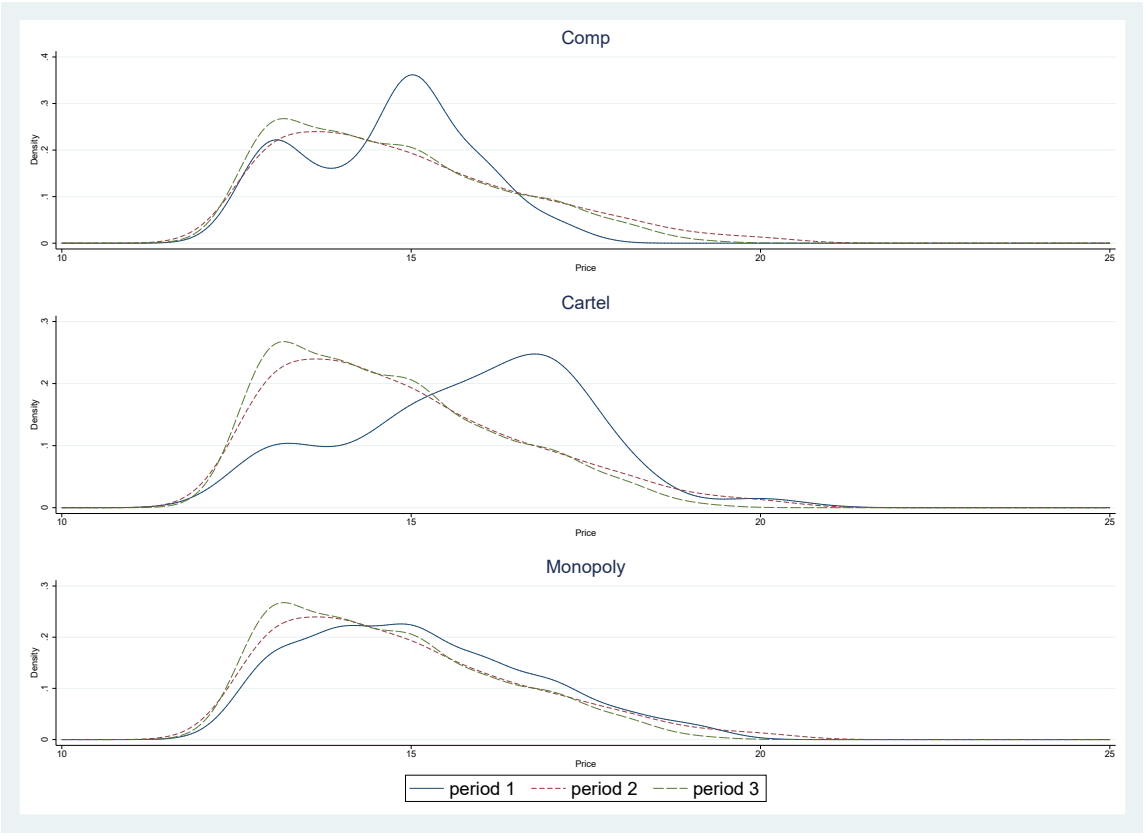
On average, trading prices under Monopoly are lower than those predicted by the theory in the case the monopolist applies a unique price (Null hypothesis: $p^*_{Mo-U} = 17$, t-test, *P-value* < 0.01) and in the case of price discrimination (Null hypothesis: average $p^*_{Mo-D} = 16$, t-test, *P-value* < 0.01). This result strengthens the evidence of Double Auction as trading institution able to control over monopoly power (Smith and Williams [1989]). What is more, the median of the distribution of monopolistic prices is lower than predicted since the very first period (Figure 1, panel Monopoly), to then decline in periods 2-3 towards levels prevailing both under Perfect Competition and Cartel in the same two periods.

Table 3: Summary statistics of trading prices for market structures played at first

	p_{Co}	p_{Co-q}	p_{Ca}	p_{Ca-q}	p_{Mo}
Mean	14.14	14.17	14.42	14.17	14.74
Max	20	19	20	19	20
Min	12	12	12	12	12
St. dev.	1.49	1.19	1.63	1.35	1.6
Obs.	141	133	140	129	443

[5]Raw experimental data and all the statistical codes are available upon request.

Figure 1: Distribution of trading prices across periods in Comp, Cartel and Monopoly when played at first



Note: Density distributions using kernel estimator.

Our aim now is to study the monotonicity of trading prices under each market structure. By pooling observations of the three trading periods, Table 4 displays the results of a parametric two-sided t-test of the difference between the average trading price obtained in two different markets when they are played at first in the experiment.[6] These statistics confirm that the sellers' agreement in the Cartel is not binding, since prices observed in Perfect Competition and in Cartel are not significantly different. Furthermore, prices in all these markets (with or without quotas) are lower than prices observed under Monopoly.

The results of our regression model estimates reported in Table 5 are consistent with our tests. We regress observed trading prices to market structure fixed effects, considering Monopoly as benchmark. Coefficients of all the fixed effects in Model 1 are negative and significant at any conventional level. Prices in Perfect Competition are on average lower than under Monopoly of about -0.608 ($p < 0.001$). Similar results are reported when comparing with-quota markets to Monopoly (-0.577 and -0.571 for Comp-q and Cartel-q, respectively; $p < 0.001$). While Cartel markets display average levels of prices that are more similar to those prevailing in Monopoly, the difference between market structures is yet significant (-0.328; $p < 0.001$). Further, we control for possible trends along the three trading periods, by including

[6] A non-parametric two-sided Mann-Whitney test gives similar results.

Table 4: t-test of equality of trading prices in markets played at first

H_0	P-value	Result
$p_{Mo} = p_{Ca-q}$	0.000	Reject
$p_{Mo} = p_{Ca}$	0.043	Reject
$p_{Mo} = p_{Co-q}$	0.000	Reject
$p_{Mo} = p_{Co}$	0.000	Reject
$p_{Ca-q} = p_{Ca}$	0.187	Not-Reject
$p_{Ca-q} = p_{Co-q}$	0.972	Not-Reject
$p_{Ca-q} = p_{Co}$	0.834	Not-Reject
$p_{Ca} = p_{Co-q}$	0.154	Not-Reject
$p_{Ca} = p_{Co}$	0.134	Not-Reject
$p_{Co-q} = p_{Co}$	0.849	Not-Reject

the variable *Period* (Model 2). As a result, the differences between Monopoly and all other market structures yet remain significant upon the inclusion of this control. Disentangling by trading period, we find that all market structures display similar prices in the first period (Model 3). However, as market interaction unfolds, the price difference between Monopoly and any other market widens (Models 4-5), becoming highly significant in the last period (magnitude ranging from 0.750 to 1.121).

Table 5: Regression models of trading prices in markets played at first

	(1)	(2)	(3)	(4)	(5)
	Price	Price	Price|t=1	Price|t=2	Price|t=3
Comp	-0.608***	-0.602***	-0.399	-0.305	-1.030***
	(-4.08)	(-4.17)	(-1.64)	(-1.01)	(-5.23)
Comp-q	-0.577***	-0.596***	-0.287	-0.705**	-0.750***
	(-4.40)	(-4.68)	(-1.19)	(-2.96)	(-4.05)
Cartel	-0.328*	-0.352*	0.771*	-0.603*	-1.121***
	(-2.06)	(-2.42)	(2.59)	(-2.56)	(-6.45)
Cartel-q	-0.571***	-0.583***	-0.0374	-0.816***	-0.786***
	(-3.98)	(-4.22)	(-0.13)	(-3.45)	(-4.26)
Period		-0.472***			
		(-8.21)			
Constant	14.75***	15.73***	14.98***	14.75***	14.56***
	(183.81)	(107.02)	(100.92)	(100.43)	(117.78)
N	986	986	298	333	355

t statistics in parentheses; OLS regression with robust errors.

* *P-value* < 0.05, ** *P-value* < 0.01, *** *P-value* < 0.001

To summarize, we can confirm our Hypothesis 1 of weak monotonicity of prices under the following relation:

$$p_{Co} = p_{Co-q} = p_{Ca} = p_{Ca-q} < p_{Mo} \tag{2}$$

H2: Spillovers of previous markets on Monopoly. We now investigate whether monopolistic prices are affected by the formation of reference prices in previously-played market structures. In Table 6, we present the results from pairwise, parametric tests on trading prices observed under Monopoly in all treatments, so as to compare those played at first with those played later in the timeline of a treatment.

Table 6: Two-sided t-test on Monopoly played at first *vs.* after other market structures.

H_0	P-values	Result
$p_{Mo} = p_{CoMo}$	0.000	Rejected
$p_{Mo} = p_{CaMo}$	0.000	Rejected
$p_{Mo} = p_{CoCaMo}$	0.000	Rejected
$p_{Mo} = p_{CaCoMo}$	0.000	Rejected

Note: p_{Mo} refers to trading prices of Monopoly played at first in the timeline of a treatment. p_{CoMo} (resp., p_{CaMo}) refers to trading prices of Monopoly played as second market, after Perfect Competition (resp., Cartel). p_{CoCaMo} (resp., p_{CaCoMo}) represents the trading prices of Monopoly played at last, after Perfect Competition and Cartel (resp., Cartel and Perfect Competition). We merged data from market structures with and without quotas since the effect on Monopoly is the same and structures with and without quotas do not differ ($P\text{-}value < 0.001$).

Results in Table 6 show that monopolistic prices are significantly lower when the Monopoly is implemented after more competitive market structures (either Perfect Competition or Cartel). Additionally, we observe that starting the experiment with Perfect Competition or with Cartel does not produce the same spillover effect on trading prices in a later played Monopoly. Indeed, if the subjects start by playing under Perfect Competition, trading prices in Monopoly played as second market are significantly lower than if they start by playing under Cartel (two-side t-test between p_{CoMo} and p_{CaMo}, $P\text{-}value < 0.01$).

Table 7 reports the results of our regression models on trading prices under Monopoly, varying for the order of implementation – after another market structure or after other two market structures – and for the type of this order (i.e., after Comp or Cartel, if Monopoly is played as second market; after Comp and then Cartel or after Cartel and then Comp, if it is played as last market in the treatment timeline of Table 2). We consider four dummy variables accounting for the effects on monopolistic prices when Monopoly is preceded by other market structures in our treatment timeline, by considering Monopoly played at first as reference for comparisons. Models 1-2 clearly report that monopolistic prices endure the effect of previously-played structures, independently of controlling for the time trend across the three trading periods, which nonetheless boosts this effect (see variable *Period* in Model 2). In particular, the highest negative impact on monopolistic prices is found when Monopoly is played as second market just after Perfect Competition (trading prices are lower of more than 1.05 points). A lower bust still significant negative effect is found when Monopoly is played as second market after Cartel (trading prices are lower of about 0.9 points). When Monopoly is introduced as

last market of a treatment, we find similar results, with again playing under Perfect Competition rather than under Cartel at first having a higher negative effect on Monopoly prices that permeates through the market structure played as second (in Model 1, -0.818 *vs.* -0.581, for CoCa *vs.* CaCo coefficient, F-test of the difference, *P-value* $= 0.04$). More generally, and perhaps surprisingly, the combination of any two more competitive market structures (Perfect Competition followed by Cartel, and conversely) before Monopoly is introduced, rather than boosting the negative effect on monopolistic prices, impacts on them to a lesser extent than when Monopoly only follows one of these two structures. Results remain unchanged upon the inclusion of the variable Period (Model 2) and by analysing the data separately, period by period (Models 3-5).

Table 7: Regression models of Monopoly prices after other market structures

	(1)	(2)	(3)	(4)	(5)
	Price	Price	Price|t=1	Price|t=2	Price|t=3
Comp (Co)	-1.053***	-1.064***	-1.311***	-0.918***	-0.976***
	(-12.54)	(-12.65)	(-9.32)	(-5.73)	(-7.26)
Cartel (Ca)	-0.890***	-0.898***	-0.824***	-0.862***	-1.010***
	(-10.00)	(-10.23)	(-4.95)	(-5.48)	(-7.58)
CoCa	-0.818***	-0.838***	-1.124***	-0.779***	-0.585***
	(-9.93)	(-10.03)	(-8.06)	(-5.45)	(-3.95)
CaCo	-0.581***	-0.587***	-0.460*	-0.627**	-0.669***
	(-5.11)	(-5.25)	(-2.23)	(-3.24)	(-3.70)
Period		-0.172***			
		(-4.38)			
Constant	14.75***	15.11***	14.98***	14.75***	14.56***
	(260.25)	(148.70)	(143.30)	(142.50)	(167.09)
Observations	1786	1786	564	591	631

t statistics in parentheses. OLS models with robust errors.

* *P-value* < 0.05, ** *P-value* < 0.01, *** *P-value* < 0.001

H3: Price discrimination in Monopoly. We now focus on the ability of monopolists to discriminate among buyers with different maximum willingness to pay. Recall that in the test of H1 we find that, when Monopoly is played at first, monopolists set on average lower prices than those theoretically predicted in the case of price discrimination (see Table 3 and Figure 1). However, here we aim at studying differences in price dispersion under Monopoly according to the order and type of order of its implementation in the treatment sequence.

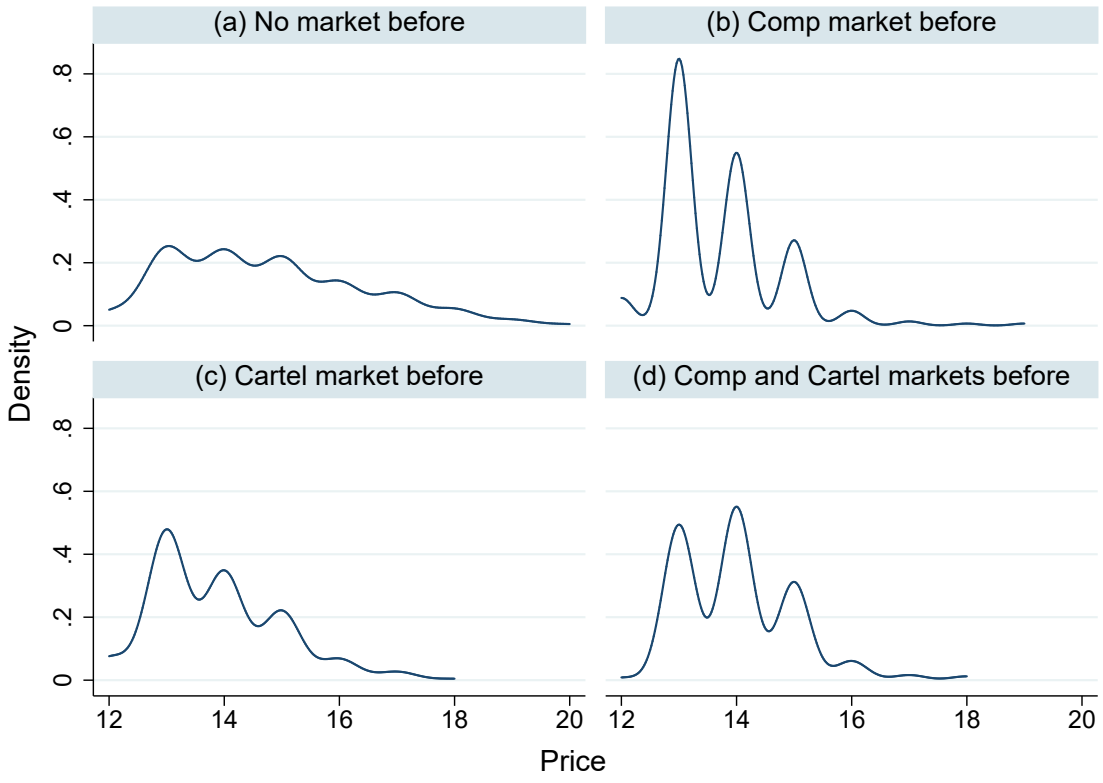
Figure 2 depicts the distribution of monopolistic prices according to the fact that, in the treatment timeline of Table 2, Monopoly is introduced at first (panel (a)), as second market after Perfect Competition (panel (b)), as second market after Cartel

(panel (c)), or at the end of the sequence, after both these markets, independently of their order (panel (d)).

Despite a lower than predicted average trading price (see Table 3 and Figure 1), when Monopoly is played at first, monopolists seem to be able to discriminate among buyers. In fact, most of the prices $p > c = 12$ that could be afforded by the buyers given their budget constraint ($p \in \{13, 14, ..., 19\}$), are actually paid (see panel (a) of Figure 3). However, Figure 3 also shows that when we look at Monopoly played after some other market structures, price discrimination is less obvious. That is, when buyers and sellers go through Perfect Competition, Cartel or both of them before being exposed to Monopoly, sellers – finally becoming monopolists – are much less able to exploit their market power.

To prove these results, we study the variance of trading prices across the four monopolies considered in Figure 3. If price discrimination is favoured when Monopoly is played at first, we should observe a higher variance of monopolistic prices under this sequence than when Monopoly is later introduced. Pairwise-parametric tests on the variance of monopolistic price distributions show that trading prices under Monopoly played at first have higher variance than under Monopoly played after any possible sequence of other market structures (standard-deviation ratio test, *P-value* < 0.01 in every case).

Figure 2: Distribution of trading prices in Monopoly under different treatments (orders)



Note: Density distributions using kernel estimator.

5 Conclusions

In this paper we analyze different market structures with few sellers and many buyers, under the same trading institution: double auction.

First of all, we strengthen previous experimental evidence showing that double-auction trading mechanisms can recreate perfectly competitive environments (Smith and Williams [1989, 1981], Davis and Williams [1991], Attanasi et al. [2020]). Indeed, prices prevailing in our perfectly competitive markets converge towards theoretically predicted equilibrium levels, despite the fact that the fraction of buyers in the market is six times as much the fraction of sellers. Similarly, when cartel opportunities are open to sellers, they do not reach mutual agreement on prices, consistently with previous experimental literature (Huck et al. [2001]).

Second, while the experimental literature provides indication that double-auction trading mechanisms cannot control over monopoly power (Muller et al. [2002], Ledyard and Szakaly-Moore [1994], Brown-Kruse et al. [1995], Godby [2002]), we provide evidence that monopoly power can be significantly resized under double-auction institutions. In fact, trading prices under monopoly are significantly lower than those predicted by the theory: double-auction trading institutions succeed in preventing monopolists to fully extract buyers' maximum willingness to pay.

Our third and most important finding concerns spillovers of previous market trading on prices prevailing in monopolistic markets. Monopolists' power is sensitive to past trading experience and to the formation of reference prices in previous (more competitive) market structures. Market spillovers play a fundamental role in weakening monopolists' ability to price discriminate in our double-auction setting. In fact, when a monopolistic market is not preceded by any other market structure, price discrimination seems more effective. However, perfectly competitive markets, as well as cartel structures, reduce the possibility of price discrimination in later-played monopoly. In other words, prices formed under perfect competition or through nonbinding cartel agreements permeate buyers and sellers' behavior in later-played monopolies, with the result being that monopolists are less likely to implement price discrimination.

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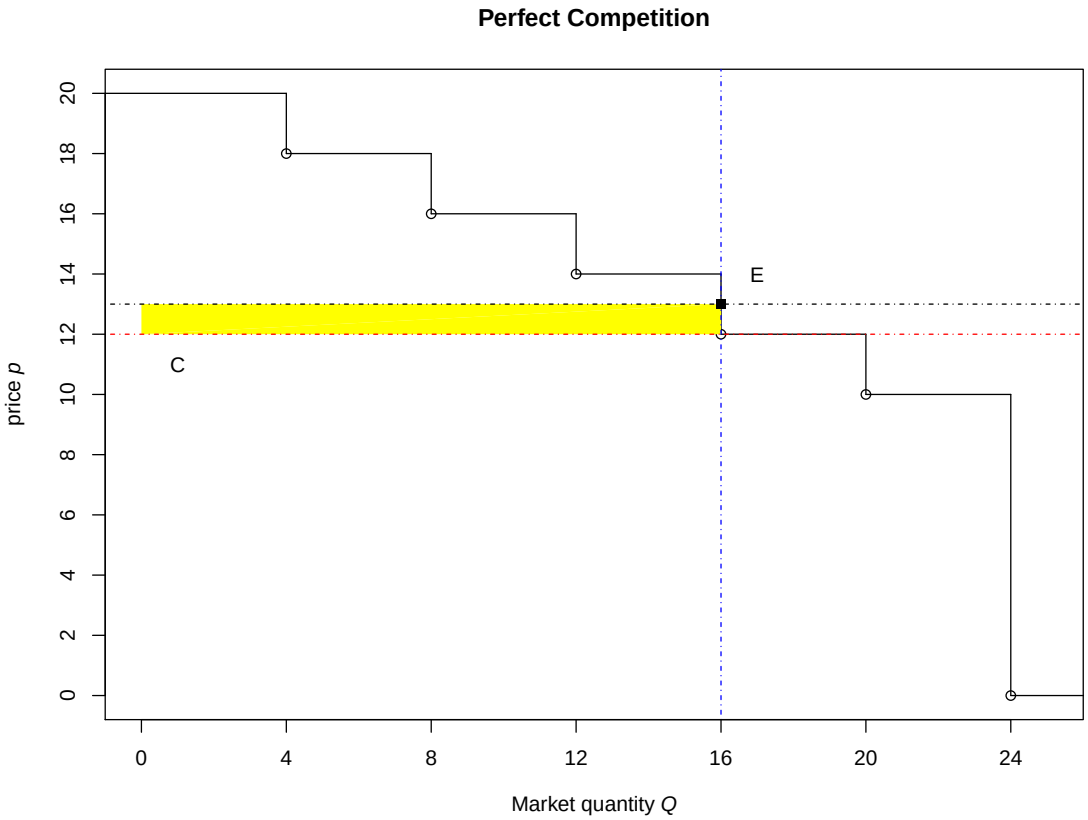
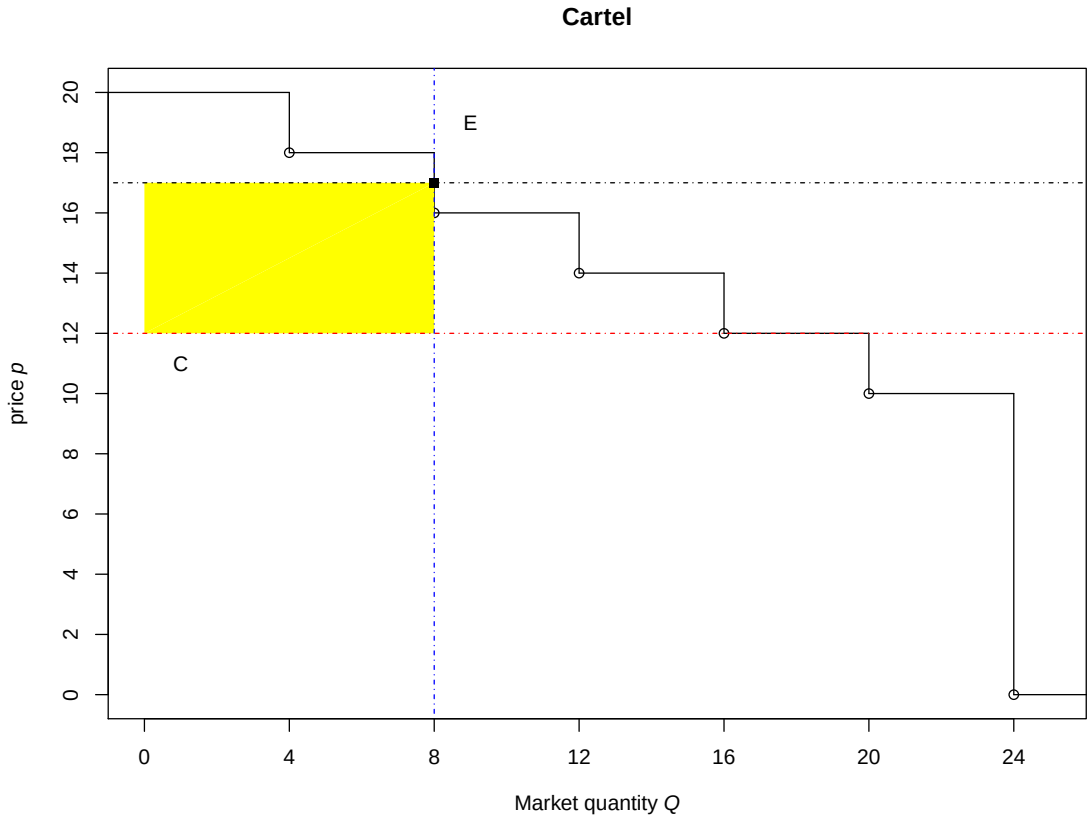
Appendix: Supplementary Figures

Figure A1: Demand and Cost function under Perfect Competition



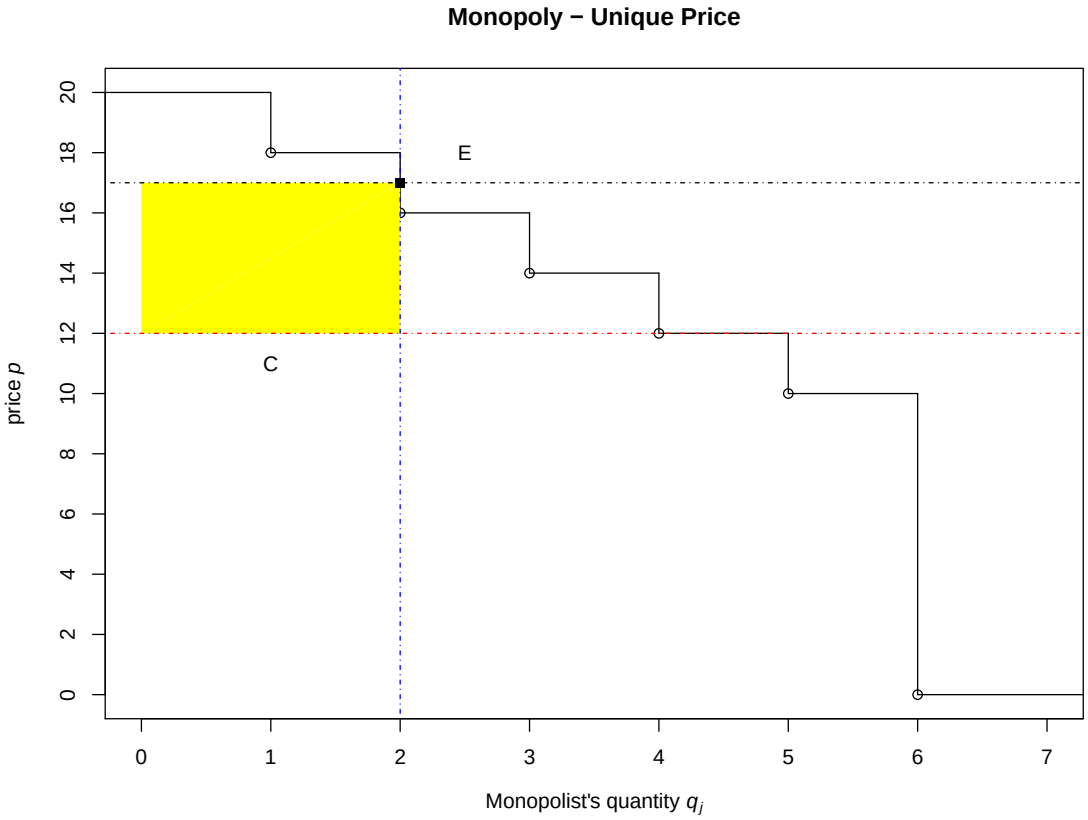
Note: the yellow area represents the sellers' surplus.

Figure A2: Demand and Cost function under Cartel



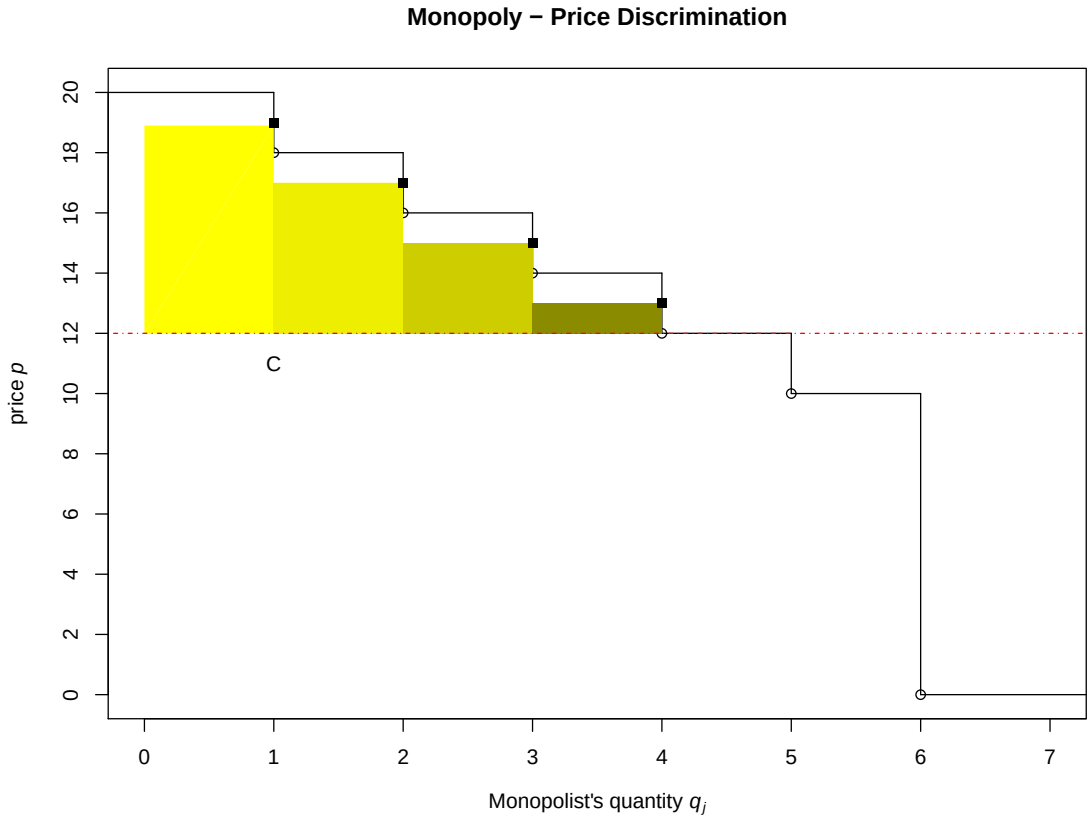
Note: the yellow area represents the sellers' surplus.

Figure A3: Demand and Cost function under Monopoly with unique price



Note: the yellow area represents monopolist j's surplus ($j = 1, 2, 3, 4$).

Figure A4: Demand and Cost function under Monopoly with price discrimination



Note: the sum of colored areas represents monopolist j's surplus ($j = 1, 2, 3, 4$).

Figure A5: Example of a buyer's computer screen during the experiment.

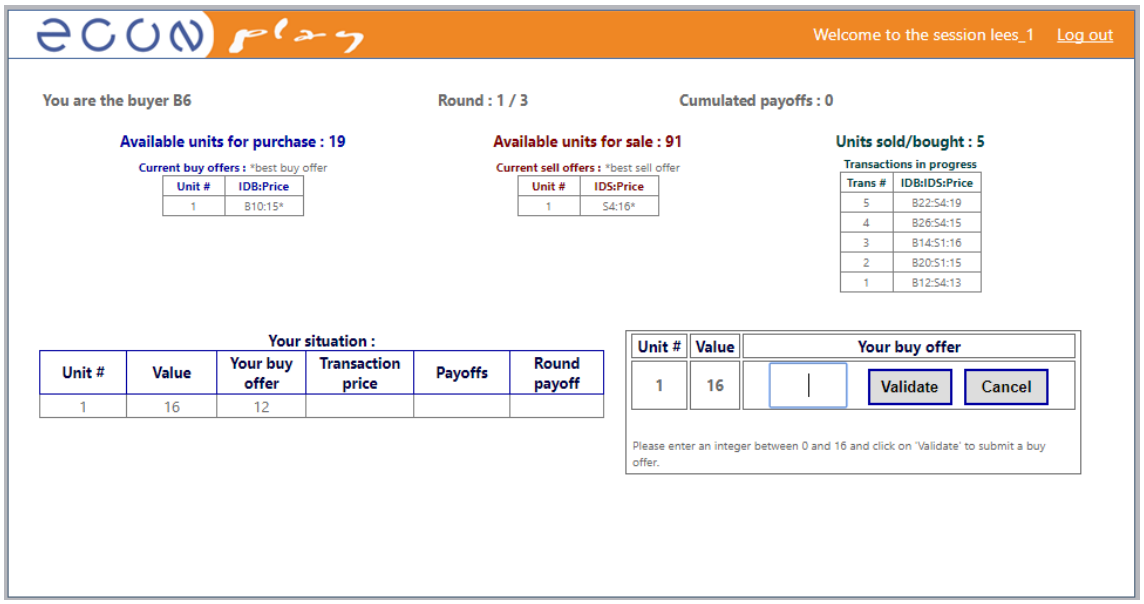
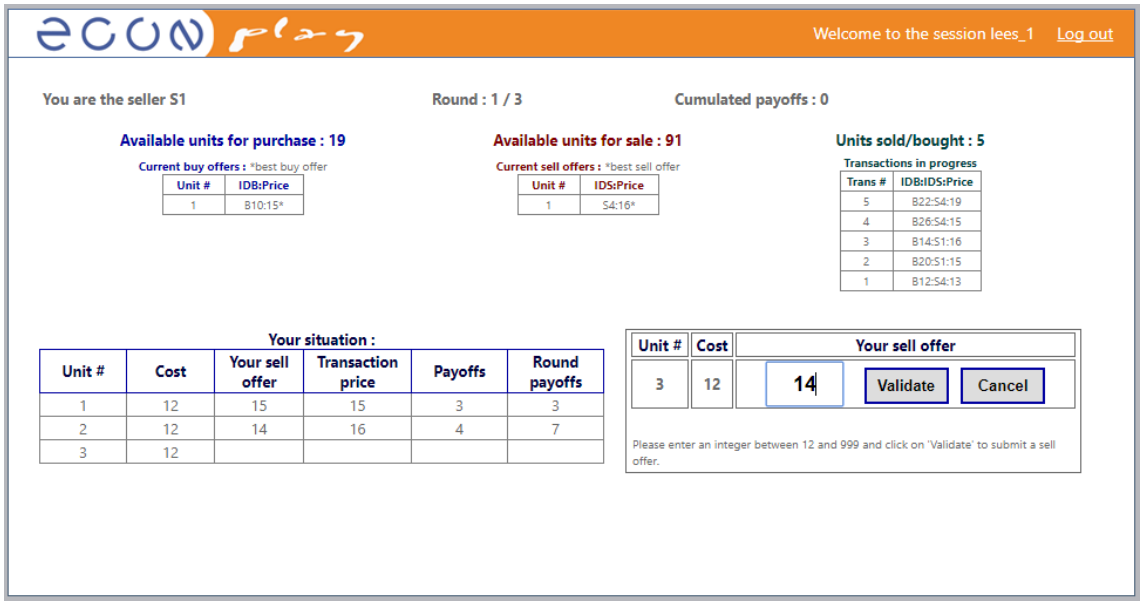


Figure A6: Example of a seller's computer screen during the experiment.



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